nicated during the hour to which the exercise is confined, when the number of students in the recitation-room is thirty, forty, or even fifty? What a perversion of the purposes of the noble endowments for higher education, to expend almost the entire energy of the teaching force of the many institutions which adopt this system, in a daily effort to weigh with minutest accuracy the fidelity with which assigned tasks have been committed to *memory!* The most diverse views may be entertained as to whether the college course can embrace analytical mechanics, or the theory of determinants (now so universally used), or whether it can omit vector and quaternion analysis. When, however, it is known that in a small western college graduating less than a dozen annually, we have now had for years volunteer classes, pursuing all these and other subjects annually, with success, the possibility of including them in a college curriculum must be acknowledged.

In conclusion, Professor Eddy wished to call for reform in our mathematical teaching. Let it not be so conducted that he who has neither taste for the study, nor special knowledge of it, stands on an equal footing as a teacher with the man of real mathematical insight. Now is a favorable time for revising our estimates of what can and ought to be done in this field. Higher mathematical culture has commenced a new and fruitful growth in this country in various places; and an association of the mathematicians of this country might be of service for the purpose of concerted action in improving the mathematical training in our colleges.

WHAT IS ELECTRICITY?[1]

ALL Professor Trowbridge hoped to do was to make his audience ask themselves the question with more humility and a greater consciousness of ignorance. We shall probably never know what electricity is, any more than we shall know what energy is. What we shall be able, probably, to discover, is the relationship between electricity, magnetism, light, heat, gravitation, and the attracting force which manifests itself in chemical changes. Fifty years ago scientific men attached a force to every phenomenon of nature: thus there were the forces of electricity and magnetism, the vital forces, and the chemical forces. Now we have become so far unitarian in our scientific views, that we accept treatises on mechanics which have the one word 'Dynamik' for a title; and we look for a treatise on physics which shall be entitled 'Mechanical philosophy,' in which all the phenomena of radiant energy, together with the phenomena of energy which we entitle electricity and magnetism, shall be discussed from the point of view of mechanics. What we are to have in the future is a treatise which will show the mechanical relation of gravitation, of so-called chemical attracting force, and electrical attracting force, and the manifestations of what we call radiant energy. We have reduced our knowledge of electricity and magnetism to what may be called a mechanical system, so that in a large number of cases we can calculate beforehand what will take place, and we are under no necessity of trying actual experiments. It is probable, for instance, that the correct form of a dynamo-machine for providing the electric light can be calculated and the plans drawn with as much certainty as the diagrams of a steam-engine are constructed. We may congratulate ourselves, therefore, in having a large amount of systematic knowledge in electricity: and we see clearly how to increase this systematic knowledge; for we have discovered that a man cannot expect to master the subject of electricity who has not made himself familiar with thermo-dynamics, with analytical mechanics, and with all the topics now embraced under the comprehensive title of 'physics.'

Out of all the theories of electricity, the two-fluid theories, the one-fluid or Franklin theory, and the various molecular theories, not one remains to-day under the guidance of which we are ready to march onward. We have discovered that we cannot speak of the velocity of electricity. All that we can truly say is, we have a healthy distrust of our theories, and an abiding faith in the doctrine of the conservation of energy.

It is one thing to become familiar with all the applications of the mechanical theory of electricity, and another to make an advance in the subject so that we can see the relations of electrical and magnetic attraction to the attraction of gravitation and to what we call chemical attraction. To this possible relationship, Professor Trowbridge wished to call attention. The new advances in our knowledge of electrical manifestations are to come from the true conception of the universality of electrical manifestations, and from the advance in the study of molecular physics. When we let an acid fall from the surface of a metal, the metal takes one state of electrification and the drop of acid the other: in other words, we produce a difference of electrical potential. On the other hand, a difference of electrical potential modifies the aggregation of molecules. The experiments of Lippman are well known. He has constructed an electrometer and even a dynamo-electric machine which depend upon the principle that the superficial energy of a surface of mercury covered with acidulated water is modified when a difference of electrical potential is produced at the limiting surfaces. The manifestations of what is called superficial energy, — that is, the energy manifested at the surface of separation of any two substances, — and the effect of electricity upon the superficial energy, afford much food for thought. There have always been two parties in electricity, — one which maintains that electricity is due to the contact of dissimilar substances, and the other party which believes that the source of electrical action must be sought in chemical action. Thus, according to one party, the action of an ordinary voltaic cell is due to the contact, for instance, of zinc with copper; the acid or solution of the cell merely acting as the connecting

[1] Abstract of an address before the section of physics of the American association for the advancement of science, at Philadelphia, Sept. 4, by Prof. JOHN TROWBRIDGE of Harvard college, Cambridge, vice-president of the section.

link between the two. According to the other party, it is to the difference of the chemical action of the metals on the connecting liquid, that we must attribute the rise and continuance of the electrical current. The electromotive force of a voltaic cell is undoubtedly due to the intrinsic superficial manifestation of energy when two dissimilar metals are placed in connection with each other either directly or through the medium of a conducting liquid. The chemical action of the liquid brings new surfaces of the metals constantly in contact; moreover, we have the difference of superficial energy between the liquid and the metals, so that our expression for electromotive force is far from being a simple one: it contains the sum of several modifications of superficial energy at the surfaces of the two metals and at the two boundaries of the liquid and the metals.

We have again a development of electromotive force by the mere contact of the metals at different temperatures. The electrical current that arises is due to the difference of superficial energy manifested at the surface of the two junctions. We know that the action is on the surface, for the size of the junctions does not affect the electromotive force. Suppose that we should make the metals so thin that an ultimate molecule of iron should rest against an ultimate molecule of copper, should we not arrive at a limit, at a definite temperature of the conversion of molecular vibration into electrical energy? And also, when our theory is perfected of the number of molecules along a linear line of copper against a linear line of zinc which can produce a current of electricity of a given strength, — the jostling, so to speak, of these ultimate molecules of two metals at different temperatures might form a scientific unit of electromotive force in the future science of physical chemistry. By means of an alloy we can apparently modify the superficial energy at the surface of a solid. Thus an alloy with a parent metal will give a varying electromotive force. If we could be sure that an alloy was always of a definite chemical composition, and not a more or less mechanical admixture, it seems as if we could get closer to the seat of electromotive force by a number of quantitative measurements. Unfortunately, the physical nature of alloys is not definitely known, and there is little coherence or regularity in our measurements of their electromotive force. We can modify the superficial energy of metals, not only by melting metals together, but also by grinding them to a very fine powder, and compressing them again by powerful means into solids more or less elastic, and then examining their superficial energy which is manifested as electromotive force. Professor Trowbridge is still engaged upon researches of this nature; and, if the work is not brilliant, he hopes that it will result in the accumulation of data for future generalization.

The subject of thermo-electricity has been eclipsed by the magnificent development of the dynamo-electric machines; but we may return to thermo-electricity as a practical source of electricity. Professor Trowbridge has been lately occupied in endeavoring to modify the difference of potential of thermo-electric junctions by raising one junction to a very high temperature under great pressure; for it is well known that the melting-point of metals is raised by great pressure. If the metal still remains in the solid state under great temperature and great pressure, can we not greatly increase the electromotive force which results from the difference of superficial energy manifested at the two junctions?

It is evident that our knowledge of electricity will increase with our knowledge of molecular action, and our knowledge of molecular action with that which we call attractive force. It is somewhat strange, that, although we are so curious in regard to electricity, we seldom reflect that gravitation is as great a mystery as electrical attraction. What is the relation between electricity and magnetism and gravitation and what we call the chemical force of attraction?

The question of the connection between electricity and gravitation dwelt much in Faraday's thoughts. He failed, however, to find the slightest relation between gravitation and electricity; and he closes his account of his experiments with these words: "Here end my experiments on this subject for the present, but I feel the conviction that there must be some connection between electricity and gravitation." Was the direction in which he experimented the true direction to look for a possible relation? and cannot the refined instruments and methods of the electrical science of the present aid us in more promising lines of research? If we could prove that whenever we disturb the relative position of bodies, or break up the state of aggregation of particles, we create difference of electrical potential; and, moreover, if we could discover that the work that this electrical potential can perform, together with the heat that it developed by the process, is the complete work that is done on the system against attractive force, or as so-called chemical attractive force, — we should greatly extend our vision of the relation of natural phenomena. And thus pursuing the line of argument of his address, Professor Trowbridge ventured to state an hypothetical law which it seemed to him is at least plausible: That "whenever the force of attraction between masses or molecules is modified in any way, a difference of electrical potential results." Is it not reasonable to suppose that certain anomalies which we now find in the determinations of specific heats of complicated aggregation of molecules are due to our failure to estimate the electrical equivalent of the movements and interchanges of the molecules? Let us take the case of friction between two pieces of wood: is it not possible that the friction is the electrical attraction which results from the endeavor to connect the phenomenon of superficial energy with electrical manifestations, that the friction between two surfaces is modified by keeping these surfaces at a difference of electrical potential? In Edison's motophone, we see this exemplified in a very striking manner.

Professor Trowbridge's own studies have been chiefly in the direction of thermo-electricity and in the subject of the electrical aspect of what we call superficial energy. These experiments so far deepen the belief that any change in the state of aggregation of

particles, — in other words, any change which results in a modification of attracting force, — whether gravitative or the commonly called chemical attracting forces, results in an electrical potential; and conversely, that the passage of electricity through any medium produces a change of aggregation of the molecules and atoms. If we suppose that radiant energy is electro-magnetic, cannot we suppose that it is absorbed more readily by some bodies than by others, or, in other words, that its energy is transferred, so that with the proper sense we would perceive what might be called electrical color, or, in other words, have an evidence of transformations of radiant energy other than that which appeals to us as light and color? We have arrived at the point in our study of electricity where our instruments are too coarse to enable us to extend our investigations. Is not the physicist of the future to have instruments delicate enough to measure the heat equivalent of the red and the yellow and the blue violet rays of energy? instruments delicate enough to discover beats of light as we now discover those of sound? The photographer of to-day speaks in common language of handicapping molecules by mixing gums with his bromide of silver, in order that their rate of vibration may be affected by the long waves of energy. Shall we not have the means of obtaining the mechanical equivalent of such handicapped vibrations? We have advanced; but we have not answered the question which filled the mind of Franklin, and which fills men's minds to-day: What is electricity?

CHEMICAL AFFINITY.[1]

PROFESSOR LANGLEY first reviewed the history of chemical theory, and called attention to the final extinction of the term 'affinity' in the chemical literature of the present day.

Shortly after the opening years of the present century, three general methods were indicated for the study of the force of affinity. Instead of being successively taken up and abandoned, like all preceding speculations, they have remained steadily in use during the eighty years which have intervened, and to-day they are still the most promising means at our disposal. These three methods may be called the thermal, the electrical, and the method of time or speed. It will be convenient to consider each one separately.

The most important generalization to be drawn from thermo-chemical phenomena is, that the work of chemical combination, or the total energy involved in any reaction, is very largely influenced by the surrounding conditions of temperature, pressure, and volume; and the conclusion they force upon us in regard to the nature of affinity is most important, namely, that this force in accomplishing work is dependent, like all other forces, on the conditions exterior to the reacting system which limit the possible amount of change. Affinity is therefore at last definitely removed from the category of those mystical agents, so often imagined by our predecessors in a less critical age, which had no correlation with the general forces of nature.

Under the title 'dissociation,' St. Claire Deville gave to the chemical world, in 1857, a new and fruitful method of investigating the nature of compounds by determining the temperature at which bodies break up or are dissociated. The laws developed by Deville and his successors in this field show us, that, after the point is reached at which decomposition commences, the further breaking up is determined by the pressure of the evolved products of the reaction, so that the permanence of the body depends on the magnitude of two variables, pressure and temperature, either of which may be varied at will through a wide range.

The electrical method of dissecting chemical forces has been followed less actively than the thermal one. Besides the well-known experimental contributions of Davy, Becquerel, and Faraday, may be mentioned Joule's researches on the heat absorbed during electrolysis, and especially the work of C. R. Adler Wright, on the 'determination of affinity as electromotive force.' The general outcome of these researches is, that the products of electrolysis are so numerous, and so varied by the results of secondary actions, that it is very doubtful whether the electromotive force measured is that due solely to the union of those atoms which are indicated by the principal equation of the reaction.

The method of time or speed of chemical reactions has a history as old as that of its two associates; but the story is much less eventful, for very little work has been done in this field. The most notable work has been done by Gladstone and Tribe, by ascertaining the rate at which a metallic plate could precipitate another metal from a solution.

To these general methods for studying the problems of chemical dynamics, should be added the investigation of the action of mass, by Gladstone, in his well-known color work on the sulphocyanide of iron; of the chemical action of light, by the late J. W. Draper in this country, and Prof. H. E. Roscoe in England, as well as Becquerel in France, — pioneers who have since been followed by a host of students of scientific photography.

In the review just given, no attempt has been made to do more than glance at the important contributions to the theory and methods of measuring affinity. Many names have been passed by, and much work has been necessarily ignored.

The history of the various modifications and additions which have been made to the primitive conception of the nature of affinity, when briefly summarized, appears to be this: Hippocrates held that union is caused by a kinship, either secret or apparent, between different substances. Boerhaave believed affinity to be a *force* which unites unlike substances. Bergman and Geoffroy taught that union is caused by a selective attraction; and therefore they called it 'elective affinity.' Wenzel and his success-

[1] Abstract of an address to the section of chemistry of the American association for the advancement of science, at Philadelphia, Sept. 4, by Prof. J. W. LANGLEY, of the University of Michigan, Ann Arbor, Mich., vice-president of the section.